Anesthesiology 2007; 106:226–37

Perioperative Cardiac Arrests in Children between 1988 and 2005 at a Tertiary Referral Center

A Study of 92,881 Patients

Randall P. Flick, M.D.,* Juraj Sprung, M.D., Ph.D.,† Tracy E. Harrison, M.D.,‡ Stephen J. Gleich, M.S.,§ Darrell R. Schroeder, M.S.,‖ Andrew C. Hanson, B.S.,# Shonie L. Buenvenida, R.N., C.C.R.P.,** David O. Warner, M.D.††

CME This article and its accompanying editorial have been selected for the *Anesthesiology* CME Program. After reading both articles, go to http://www.asahq.org/journal-cme to take the test and apply for Category 1 credit. Complete instructions may be found in the CME section at the back of this issue.

Background: **The objective of this study was to determine the incidence and outcome of perioperative cardiac arrest (CA) in children younger than 18 yr undergoing anesthesia for noncardiac and cardiac procedures at a tertiary care center.**

Methods: **After institutional review board approval (Mayo Clinic, Rochester, Minnesota), all patients younger than 18 yr who had perioperative CA between November 1, 1988, and June 30, 2005, were identified. Perioperative CA was defined as a need for cardiopulmonary resuscitation or death during anesthesia care. A cardiac procedure was defined as a surgical procedure involving the heart or great vessels requiring an incision.**

Results: **A total of 92,881 anesthetics were administered during the study period, of which 4,242 (5%) were for the repair of congenital heart malformations. The incidence of perioperative CA during noncardiac procedures was 2.9 per 10,000, and the incidence during cardiac procedures was 127 per 10,000. The incidence of perioperative CA attributable to anesthesia was 0.65 per 10,000 anesthetics, representing 7.5% of the 80 perioperative CAs. Both CA incidence and mortality were highest among neonates (0–30 days of life) undergoing cardiac procedures (incidence: 435 per 10,000; mortality: 389 per 10,000). Regardless of procedure type, most patients who experienced perioperative CA (88%) had congenital heart disease.**

Conclusion: **The majority of perioperative CAs were caused by factors not attributed to anesthesia, in distinction to some recent reports. The incidence of perioperative CA is manyfold higher in children undergoing cardiac procedures, suggesting that definition of case mix is necessary to accurately interpret epidemiologic studies of perioperative CA in children.**

This article is accompanied by an Editorial View. Please see: Morray JP, Posner K: Pediatric perioperative cardiac arrest: In search of definition(s). ANESTHESIOLOGY 2007; 106:207–8.

IDENTIFICATION of risk factors and analysis of potentially correctable causes for perioperative cardiac arrest (CA) may lead to improvements in perioperative techniques. For example, reports of the high incidence of "curare deaths" in late 1950s,[1] airway obstruction in early 1960s,[2,3] and inadequate ventilation and medication-related events (especially anesthetic overdose) in subsequent decades[4,5] prompted specific recommendations for changes in practice to address factors leading to these events. Whether these changes have in fact decreased the frequency of perioperative CA or mortality remains controversial,[4,6–13] but analysis of perioperative CA remains a potentially valuable method to decrease perioperative morbidity and mortality.

Several studies of perioperative CA over prior decades have included pediatric patients.[1,4,5,7,9,11,14–16] An early study showed that children have a higher incidence of perioperative CA compared with adults (14 *vs.* 3.7 per 10,000, respectively),[1] and within the pediatric population, perioperative CA is more frequent in infants than in older children.[11,14] To further study perioperative CA in children, the Pediatric Perioperative Cardiac Arrest (POCA) Registry was created in 1994 and has provided valuable insights.[11] However, as with all registries, there are significant limitations regarding the consistency of case ascertainment and available information pertaining to the underlying case mix. In particular, this registry and many other studies do not distinguish between the incidence of perioperative CA in children undergoing cardiac and noncardiac surgeries. Both the frequency and the etiology of perioperative CA may differ significantly between these populations, so that such distinctions may be important to adequately understand the problem.

The objectives of this study were to determine the incidence and outcome of perioperative CA in children younger than 18 yr undergoing both noncardiac and cardiac procedures requiring anesthesia services. This represents the largest report to date from a single institution of the incidence of perioperative CA analyzed separately in noncardiac and cardiac procedures.

* Assistant Professor of Anesthesiology, † Professor of Anesthesiology, ‡ Fellow in Anesthesiology, § Medical Student, Mayo Medical School (on Anesthesia Rotation), ** Certified Clinical Research Professional, †† Professor of Anesthesiology, Department of Anesthesiology, Mayo Clinic College of Medicine. ‖ Assistant Professor of Biostatistics, # Data Analyst, Department of Health Sciences, Mayo Clinic.

Received from the Department of Anesthesiology, Mayo Clinic College of Medicine, Rochester, Minnesota, and the Department of Health Sciences, Mayo Clinic, Rochester, Minnesota. Submitted for publication July 11, 2006. Accepted for publication October 9, 2006. Support was provided solely from institutional and/or departmental sources.

Address correspondence to Dr. Sprung: Department of Anesthesiology, Mayo Clinic College of Medicine, 200 First Street Southwest, Rochester, Minnesota 55905. sprung.juraj@mayo.edu. Individual article reprints may be accessed at no charge through the Journal Web site, www.anesthesiology.org.

Materials and Methods

Study Population

After Mayo Clinic institutional review board approval, we ascertained all perioperative CAs that occurred during procedures requiring anesthesia services in children younger than 18 yr undergoing anesthesia at Mayo Clinic, Rochester, Minnesota, between November 1, 1988, and June 30, 2005. All identified charts were authorized for review by the institutional review board. Our electronic Anesthesia Quality Assurance system (Performance Improvement Database), an information source used in the current study, became effective on November 1, 1988. All patients who require anesthesia services are included: inpatients, outpatients, and all procedures (radiologic imaging such as magnetic resonance imaging and/or computerized axial tomography scanning, bronchoscopy, endoscopy, and other interventional procedures including cardiac catheterizations).

As part of the department's performance improvement efforts, all anesthesia providers must report critical incidents, including perioperative CA. A Performance Improvement Committee, consisting of staff anesthesiologists, anesthesia chief residents, certified nurse anesthetists, and recovery room nurses meets monthly to review all incidents. To confirm perioperative CA ascertainment, we also reviewed the Mayo Clinic electronic medical record to identify all pediatric patients who were indicated to have died within 1 day of a surgical procedure. Finally, the Performance Improvement Database was reviewed for the following additional key words: *unexpected intubation*, *reintubation*, or *change in cardiac status*. Neither review disclosed any additional perioperative CAs not captured in the Performance Improvement database.

We defined a perioperative CA as an event that required cardiopulmonary resuscitation with closed or open chest compressions, or "death," while in the continuous care of the anesthesia team, *i.e.*, intraoperative CA or CA during recovery from anesthesia in the postanesthesia care unit. CAs occurring in patients who underwent congenital heart operations and who failed weaning from cardiopulmonary bypass (CPB) were counted as perioperative CAs. Only events occurring after the assumption of care by the anesthesia team (from entry of the patient into the operating or procedure room until care was transferred to intensive care unit or floor personnel) were included. Patients were included only if there was a detectable blood pressure at the time that anesthesia care commenced. The following categories were excluded: (1) events that were coded as "cardiac arrest" in the database but were resolved with only airway intervention (tracheal intubation, mask ventilation) without chest compressions (n = 2); (2) patients who were brought to the operating room and failed an effort to discontinue previously established extracorporeal membrane oxygenation (n = 5); (3) brain-dead patients brought to the operating room for organ retrieval (n = 7); and (4) patients "in extremis," *i.e.*, those who were already receiving chest compressions on arrival to the operating room (n = 16).

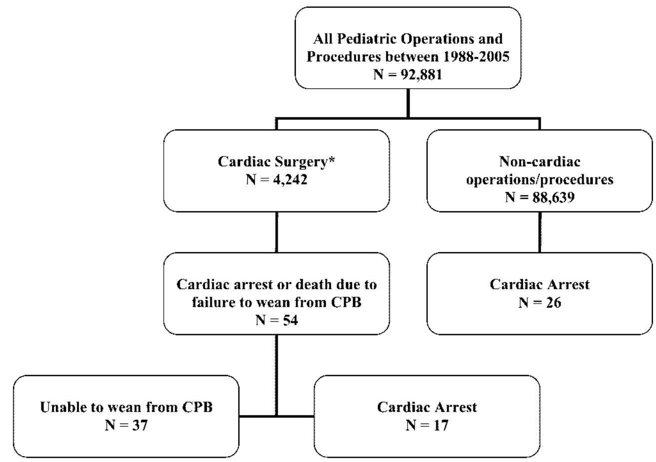
Rates were derived from the total number of cases requiring anesthesia services obtained from the Mayo Clinic anesthesia and surgery databases, including a data set specific to the Division of Cardiovascular Surgery Research. The medical records of all patients identified as having a perioperative CA were abstracted by one of three individual reviewers (T.E.H., S.L.B., and S.J.G.). Any uncertainties arising from this primary abstraction were resolved by the consensus opinion of the two senior authors (R.P.F., and J.S.). This method of case ascertainment was similar to that used in a previous report from our institution of perioperative CA of patients of all ages undergoing noncardiac surgery.[17] The current study differs from the previous report by including (1) children undergoing cardiac procedures, (2) procedures performed at locations remote from the operating suite (*e.g.*, imaging studies) that required anesthesia services, and (3) a longer period of time (November 1, 1988, to June 30, 2005).

Data Analysis

The primary objective of this study was to describe the incidence and causes of perioperative CA. Rates (per 10,000 anesthetics) were calculated both for all procedures and also separately for cardiac and noncardiac procedures. A cardiac procedure was defined as a surgical procedure involving the heart or great vessels that required a surgical incision. This included all cases using CPB. All other procedures, including cardiac catheterization (therapeutic or diagnostic) and other diagnostic or nonsurgical therapeutic procedures, were defined as noncardiac procedures. Rates were also calculated according to calendar time (using 5-yr intervals) and patient age (0 to 30 days [neonates], 31 to 365 days [infants], 1 to 3 yr, 4 to 9 yr, and 10 to < 18 yr). Although the study represents a complete enumeration of all procedures performed during the study period, 95% confidence intervals are presented along with the observed rates to aid interpretation of the current study and the comparison with findings from other investigations.

Probable causes of perioperative CAs were classified as (1) hypovolemia caused by hemorrhage or sepsis, including CA caused by the consequences of resuscitation (*e.g.*, hyperkalemia due to rapid blood administration); (2) primary cardiac (*e.g.*, dysrhythmias, including those caused by anesthetic agents, heart injury during cardiac catheterization); (3) hypoxia (*e.g.*, airway or endotracheal tube mishaps, pulmonary disease [pulmonary hypertension]); and (4) embolic events (*e.g.*, air embolism, thromboembolism). Attribution of perioperative CA was performed as follows by the consensus of the two senior authors (J.S., R.P.F). CA occurring after initiation of anesthesia in which anesthetic management was undoubtedly a cause for CA was classified as "anesthesia attributed" (*i.e.*, case of esophageal intubation). A CA was deemed anesthesia attributed even if the patient had severe coexisting disease (*i.e.*, sepsis) that was a threat to life but anesthesia management clearly contributed to an adverse outcome (*i.e.*, failure to recognize a vasopressor pump malfunction that led to hypotension and CA). "Non–anesthesia-attributed" CAs were caused by the patient's underlying medical condition (*e.g.*, failure to wean from the CPB regardless of cause, massive trauma, requirement for massive transfusion and its metabolic consequences, embolic events). In this regard, our attribution of perioperative CA etiology differed from that in the POCA Registry, in which the consequences of massive transfusion and embolic events were considered as anesthesia related. Injuries due to management by providers other than anesthesiologists (*e.g.*, perforation of ventricle during cardiac catheterization) were also categorized as non–anesthesia attributed.

A secondary objective was to identify potential predictors of survival after perioperative CA. This analysis was performed only for noncardiac procedures (n = 26), given the likelihood that the underlying disease is of primary importance in survival after cardiac surgery. The Fisher exact test was used to assess the association of various patient and procedural characteristics with hospital survival. Given the exploratory nature of this analysis, no adjustments were performed to account for multiple comparisons. Because of the limited number of patients that experienced perioperative CA, multivariate analysis was not performed. Patient-related factors analyzed included age, sex, American Society of Anesthesiologists physical status (ASA PS) score (for this analysis we grouped patients by ASA PS scores ≤ III or ≥ IV), and hemodynamic stability before operation or procedure ("unstable" was defined as the need for infusion of potent vasopressors before perioperative CA to maintain adequate blood pressure and/or heart rate, or hemodynamic values that are lower than expected for age). A separate subcategory of "unstable patients" was defined as those who were mechanically ventilated at arrival to the operating room. Procedure-related factors analyzed included (1) surgical *versus* diagnostic and therapeutic nonsurgical procedures, (2) emergent *versus* elective procedures, (3) duration of anesthesia before CA (≤ 1.0, 1.1 to 2.0, ≥ 2.1 h), (4) occurrence during induction or emergence *versus* anesthetic maintenance, and (5) use of invasive monitoring (arterial line and/or central venous line).



*Includes 3,033 surgeries requiring cardiopulmonary bypass

Fig. 1. Overview of study denominators and numerators. CPB = cardiopulmonary bypass.

Results

A total of 92,881 procedures requiring anesthesia services were performed in children younger than 18 yr at Mayo Clinic Rochester between November 1, 1988, and June 1, 2005. Of these procedures, 9,258 (10%) were performed in children younger than 1 yr (1,451 in children aged 0 to 30 days and 7,807 in children aged 31 to 356 days), 19,205 (21%) in children aged 1–3 yr, 25,650 (28%) in children aged 4–9 yr, and 38,768 (42%) in children aged 10 to < 18 yr. General anesthesia was used in 89.5% of these procedures. The majority of procedures were performed in children classified as ASA PS I or II (73%), with 23% classified as ASA PS III and 1.6% classified as ASA PS IV or V. A total of 88,639 anesthetics (95%) were administered for noncardiac procedures, and 4,242 (5%) were administered for cardiac procedures (fig. 1).

Perioperative CA occurred during 26 noncardiac procedures and 54 cardiac procedures (of which 37 were because of a failure to wean from CPB). Of the 26 noncardiac patients who experienced CA, 7 had congenital heart disease, such that 87.5% of all patients who experienced perioperative CA had underlying heart disease. Although numbers in each epoch examined were small, the incidence did not change dramatically over the study period (table 1). Over the study period, the overall incidence of perioperative CA (for both noncardiac and cardiac procedures) was 8.6 per 10,000 anesthetics, and the mortality associated with perioperative CA was 6.8 per 10,000 anesthetics (table 2). Of the 80 perioperative CAs, 6 (7.5%) were attributed to anesthesia. The incidence of perioperative CA and the mortality after CA were highest in neonates (tables 2 and 3).

Noncardiac Procedures

The overall incidence of perioperative CA during noncardiac procedures was 2.9 per 10,000 anesthetics (table

Table 1. Frequency of Perioperative Cardiac Arrests in Pediatric Patients by Calendar Year

	Overall				Noncardiac Surgery/Procedure				Cardiac Surgery			
			CAs per 10,000 Anesthetics				CAs per 10,000 Anesthetics				CAs per 10,000 Anesthetics	
Calendar Period*	Anesthetics, n	CAs, n	Estimate	95% CI	Anesthetics, n	CAs, n	Estimate	95% CI	Anesthetics, n	CAs, n	Estimate	95% CI
1988*–1990	9,596	13	13.5	7.2–23.2	8,895	3	3.4	0.7–9.9	701	10	142.7	68.6–260.8
		7†	7.3†	2.9–15.0†						4†	57.1†	15.6–145.5†
1991–1995	24,365	24	9.9	6.3–14.7	23,014	8	3.5	1.5–6.8	1,351	16	118.4	67.8–191.6
		15†	6.2†	3.4–10.2†						7†	51.8†	20.9–106.5†
1996–2000	27,821	23	8.3	5.2–12.4	26,609	3	1.1	0.2–3.3	1,212	20	165.0	101.1–253.7
		8†	2.9†	1.2–5.7†						5†	41.3†	13.4–96.0†
2001–2005*	31,099	20	6.4	3.9–9.9	30,121	12	4.0	2.1–7.0	978	8	81.8	35.4–160.5
		13†	4.2†	2.2–7.1†						1†	10.2†	0.3–56.8†

* Surgeries performed from November 1, 1988, to June 30, 2005, are included. Therefore, for 1988 and 2005, only part of the year is included. † Estimates after "inability to wean from cardiopulmonary bypass" were excluded.

CAs = cardiac arrests; CI = confidence interval.

2), and mortality was 1.6 per 10,000 anesthetics (table 3). The overall hospital survival for patients experiencing perioperative CA during noncardiac procedures was 46% (95% exact binomial confidence interval, 27–67%; table 4). Of these 26 patients, the majority had significant comorbidities (88.5% were ASA PS ≥ III and 50% were ASA PS ≥ IV), and the majority of perioperative CAs (73%) occurred during the procedure. Factors associated with mortality in univariate analysis included higher ASA PS, age, the need for mechanical ventilation before surgery, and the cause of perioperative CA, with the highest survival rates observed after CAs attributed to cardiac causes. Survival tended to be less in emergent operations, but this trend was not statistically significant ($P = 0.08$; table 4).

All perioperative CAs in noncardiac procedures occurred during general anesthesia except in one patient with a congenital heart anomaly (receiving monitored anesthesia care; table 5). The most common etiology of perioperative CA in noncardiac procedures was hypovolemia, including the consequences of massive blood transfusion, *i.e.*, hyperkalemia (8 patients [31%]). Eight perioperative CAs occurred in infants within 3 months of their premature birth (3 noncardiac and 5 cardiac procedures). In 6 patients (23%), perioperative CA was attributed to anesthesia (incidence of 0.65 per 10,000 anesthetics): 4 of these patients survived (66.7%), including the two patients who were ASA PS I. One of these 6 patients was ASA PS V, and was by the nature of the disease not expected to survive; however, an anesthesia-

Table 2. Frequency of Perioperative Cardiac Arrests by Age

	Overall				Noncardiac Surgery/Procedure				Cardiac Surgery			
			CAs per 10,000 Anesthetics				CAs per 10,000 Anesthetics				CAs per 10,000 Anesthetics	
Age	Anesthetics, n	CAs,* n	Estimate	95% CI	Anesthetics, n	CAs,* n	Estimate	95% CI	Anesthetics, n	CAs,* n	Estimate	95% CI
0 to 30 days	1,451	23	158.5	100.7–236.9	1,014	4	39.4	10.8–100.7	437	19	434.8	263.8–670.7
		10*	68.9*	33.1–126.4*						6*	137.3*	50.5–296.4*
31 days to 1 yr	7,807	18	23.1	13.7–36.4	7,045	3	4.3	0.9–12.4	762	15	196.9	110.6–322.6
		4*	5.1*	1.4–13.1*						1*	13.1*	0.3–72.9*
Overall < 1 yr	*9,258*	*41*	*44.3*	*31.8–60.0*	*8,059*	*7*	*8.7*	*3.5–17.9*	*1,199*	*34*	*283.6*	*197.2–394.0*
		*14**	*15.1**	*8.3–25.4**						*7**	*58.4**	*23.5–119.9**
1 to 3 yr	19,205	15	7.8	4.4–12.9	18,354	5	2.7	0.9–6.4	851	10	117.5	56.5–215.0
		8*	4.2*	1.8–8.2*						3*	35.3*	7.3–102.7*
4 to 9 yr	25,650	11	4.3	2.1–7.7	24,510	7	2.9	1.1–5.9	1,140	4	35.1	9.6–89.6
		10*	3.9*	1.9–7.2*						3*	26.3*	5.4–76.7*
10 to < 18 yr	38,768	13	3.4	1.8–5.7	37,716	7	1.9	0.7–3.8	1,052	6	57.0	21.0–123.7
		11*	2.8*	1.4–5.1*						4*	38.0*	10.4–97.1*
Total, 0 days to < 18 yr	*92,881*	*80*	*8.6*	*6.8–10.7*	*88,639*	*26*	*2.9*	*1.9–4.3*	*4,242*	*54*	*127.3*	*95.8–165.8*
		*43**	*4.6**	*3.4–6.2**						*17**	*40.1**	*23.4–64.1**

* Estimates after "inability to wean from cardiopulmonary bypass" were excluded. Italicized data represent overall incidence of cardiac arrests (CAs) for infants (overall < 1 yr) and for the entire pediatric population (total).

CI = confidence interval.

Table 3. Mortality after Perioperative Cardiac Arrests by Age

	Overall				Noncardiac Surgery/Procedure				Cardiac Surgery			
			Deaths per 10,000 Anesthetics				Deaths per 10,000 Anesthetics				Deaths per 10,000 Anesthetics	
Age	Anesthetics, n	Deaths, n	Estimate	95% CI	Anesthetics, n	Deaths, n	Estimate	95% CI	Anesthetics, n	Deaths, n	Estimate	95% CI
0 to 30 days	1,451	21	144.7	89.8–220.4	1,014	4	39.4	10.8–100.7	437	17	389.0	228.2–615.6
31 days to < 1 yr	7,807	15	19.2	10.8–31.7	7,045	0	—	—	762	15	196.9	110.6–322.6
Overall < 1 yr	*9,258*	*36*	*38.9*	*27.2–53.8*	*8,059*	*4*	*5.0*	*1.4–12.7*	*1,199*	*32*	*266.9*	*183.3–374.7*
1 to 3 yr	19,205	11	5.7	2.9–10.2	18,354	1	0.5	0.0–3.0	851	10	117.5	56.5–215
4 to 9 yr	25,650	8	3.1	1.3–6.1	24,510	4	1.6	0.4–4.2	1,140	4	35.1	9.6–89.6
10 to < 18 yr	38,768	8	2.1	0.9–4.1	37,716	5	1.3	0.4–3.1	1,052	3	28.5	5.9–83.1
Total, 0 days to < 18 yr	*92,881*	*63*	*6.8*	*5.2–8.7*	*88,639*	*14*	*1.6*	*0.9–2.6*	*4,242*	*49*	*115.5*	*85.6–152.4*

Italicized data represent overall incidence of deaths for infants (overall < 1 yr) and for the entire pediatric (total) population.
CI = confidence interval.

related event clearly contributed to his demise. Perioperative CA was caused directly as a complication of a procedure in 2 patients (incidence of 0.22 per 10,000 anesthetics). In 1 patient, perforation of the heart during atrial septostomy caused pericardial tamponade, and in a second, the coronary sinus was perforated during replacement of a Port-a-Cath® access catheter (Smiths Medical MD, Inc., St. Paul, MN).

Cardiac Procedures

The overall incidence of perioperative CA for cardiac procedures was 127.3 per 10,000 (table 2). Both the incidence of perioperative CA and mortality were highest in neonates, 435 per 10,000 (table 2) and 389 per 10,000 (table 3), respectively. No consistent trend in incidence over time was observed (table 1). None of these events were attributed to anesthesia (table 6). The incidence of perioperative CA was considerably higher in cardiac compared with noncardiac procedures (tables 1, 2, and 7). This was also true when those patients who failed to wean from CPB were excluded from the analysis (table 7).

Discussion

This study describes perioperative CA in patients younger than 18 yr occurring in a single tertiary referral center over a 17-yr period. In addition to this descriptive information, the major new finding of this study is that the large majority of perioperative CAs in children are caused by factors not related to anesthetic management. Also, perioperative CA is much more frequent in children undergoing cardiac operations, especially in neonates, a factor that can significantly affect the evaluation of the epidemiology of pediatric perioperative CA.

The epidemiology of pediatric perioperative CA has been examined in several retrospective studies,[1,5,10,18] surveys,[9,16,19] audits,[16] and a national registry.[11] The results of these studies are summarized in table 8. Variability in designs makes direct comparisons among studies difficult[2,4,5,9–11] because they differ in both their definitions of perioperative CA and the "perioperative" period, the ages of patients included, and the methods of case ascertainment. Importantly, cardiac operations are included in some studies and excluded in others. There are also relatively small numbers of events in most studies.

To overcome some of these limitations and to provide information regarding the causes and outcomes of pediatric perioperative CA, the POCA Registry was formed by the American Society of Anesthesiologists in 1994. This registry included 63 participating institutions, most of which were tertiary referral centers. Each institution was asked to submit a standardized data form for all cases of CA (defined as the administration of chest compressions or death) occurring in children younger than 18 yr during administration or recovery from anesthesia. Each institution also reported their total number and types of cases. The first report from this registry provided valuable information regarding the etiology of perioperative CA. In particular, the relatively large number of events considered to be related to anesthesia (150, representing 52% of the total number of events submitted) made possible a detailed examination of how anesthesia practices might contribute to perioperative CA. However, as acknowledged by the authors,[11] registries have significant limitations. The most significant is the potential for underreporting in this voluntary system, caused by the large amount of data required to report each case and the possibility of selection bias because more sensitive cases are not reported. Other factors make it difficult to use this registry as a means to study the epidemiology of pediatric perioperative CA. The information provided by the institutions regarding their practices did not include age or ASA PS. They also did not distinguish between the estimated incidence of CA in cardiac *versus* noncardiac procedures, nor did they report the relative proportion of cardiac surgeries in their patient population.

Table 4. Factor Associated with Survival after Perioperative Cardiac Arrest in Pediatric Patients Undergoing Noncardiac Surgery (n = 26)

Characteristic	n	Survival, n (%)	*P**
Overall	26	12 (46)	—
Sex			0.692
Male	15	6 (40)	
Female	11	6 (55)	
Age			0.040
0 to 30 days	4	0 (0)	
31 days to < 1 yr	3	3(100)	
1 to 3 yr	5	4 (80)	
4 to 9 yr	7	3 (43)	
10 to < 18 yr	7	2 (29)	
ASA PS			0.047
≤ III	13	9 (69)	
≥ IV	13	3 (23)	
Type of intervention			0.401
Diagnostic procedures	8	5 (63)	
Surgeries (excludes cardiac operations)†	18	7 (39)	
Emergency procedure/operation			0.081
No	19	11 (58)	
Yes	7	1 (14)	
Stable at arrival in operating/procedure room			0.216
No	8	2 (25)	
Yes	18	10 (56)	
Preoperative mechanical ventilation			0.021
No	15	10 (67)	
Yes	11	2 (18)	
Arterial line present before CA			0.431
No	12	7 (58)	
Yes	14	5 (36)	
Central venous line present before CA			0.391
No	19	10 (53)	
Yes	7	2 (29)	
Timing of CA			0.190
Induction/emergence	7	5 (71)	
Anesthetic course	19	7 (37)	
Duration of anesthesia before CA, h			0.883
≤ 1.0	11	6 (55)	
1.1 to 2.0	7	3 (43)	
≥ 2.1	8	3 (38)	
Cause of cardiac arrest			0.027
Massive hemorrhage	10	2 (20)	
Cardiac causes	8	7 (88)	
Hypoxic events	5	2 (40)	
Embolic events	3	1 (33)	

* Exact test. † Includes general pediatric surgery (n = 6); orthopedic (n = 4); neurologic (n = 4); ear, nose, and throat (n = 2); urologic (n = 1); and ophthalmology (n = 1).

ASA PS = American Society of Anesthesiologists physical status; CA = cardiac arrest.

Although the current single-center study has an absolute number of perioperative CAs considerably less than presented in the initial POCA Registry report, there are several features that are advantageous. We have previously demonstrated our ability to ascertain perioperative CA in a general noncardiac surgery population using the same methodology,[17] so that underreporting is unlikely. Precise information regarding the population "denominators" of age, ASA PS, and surgical procedure is available, so that the incidence of perioperative CA can be calculated for these subgroups. Therefore, our information should complement that provided by the POCA Registry to form a more complete understanding of pediatric perioperative CA in contemporary anesthesia practice.

Causes of Perioperative CA

Highlighted causes of perioperative CA in previous studies have included initial reports of "curare deaths" in the late 1950s,[1] airway-related complications in the 1960s and 1970s,[2,14,20] and inadequate ventilation and medication-related errors.[4,21] The pattern of causality in the current report differs from that in the initial POCA report.[11] In that report, 52% of CAs were attributed to anesthesia-related causes, whereas in our study, only 7.5% were anesthesia-related. Part of this difference is due to the fact that anesthesia-related CA in POCA Registry included arrests caused by massive hemorrhage (with associated transfusion related complications such as hyperkalemia), embolic events, and pulmonary hypertension, all of which we considered not attributed to anesthesia. However, even if the same definitions as the POCA report were used, only 18.8% (15 of 80) of all perioperative CAs would be related to anesthesia in the current study. A recent update of the POCA Registry (published in abstract form)[22] of 339 additional cases of perioperative CA from 1998 to 2003 found that 163 (48%) of these were related to anesthesia, showing that a strong representation of anesthesia-attributed cases continues in this registry.

There are at least two possible explanations for the difference in the proportion of anesthesia-attributed perioperative CA in the POCA Registry and our series. First, no data are presented regarding the case mix (*e.g.*, cardiac *vs.* noncardiac procedures) at the institutions participating the in the POCA Registry. Our institution has an active cardiac surgery practice, and all CAs occurring in these patients were attributed to non–anesthesia-related causes. The majority of perioperative CAs were associated with cardiac surgery in the current study (67.5%), compared with 27.7% in the POCA Registry. Furthermore, in our study, 46.3% of perioperative CAs were associated with failure to wean from CPB, whereas in the POCA Registry, this etiology comprised only 8.7% of CAs. Therefore, differences in case mix could affect the percentage of anesthesia-attributed perioperative CAs, although even when only noncardiac procedures were examined, still only 6 of 26 perioperative CAs (23.1%) were attributed to anesthesia. Second, the POCA Registry relies on self-reporting by anesthesiologists. Anesthesiologists are perhaps most concerned with events under their control and thus may be more likely to report those events that are related to anesthesia. We speculate that the higher proportion of anesthesia-attributed causes in the POCA Registry may reflect this reporting bias, and that perioperative CA is more commonly associated with non–anesthesia-related factors in current

Table 5. Perioperative Cardiac Arrests in Noncardiac Procedures: Overview of Demographics, Procedural Factors, Causes, and Survival

Year of Arrest	Age/Sex	ASA PS	Diagnosis	Operation/Procedure	Probable Cause of Arrest	Hospital Survival
1988	3 yr/F	III	Univentricular heart	Cardiac catheterization	Sudden ventricular fibrillation (NAA)	Yes
1989	40 days/F	I	Congenital cataract	Examination during anesthesia	Hypoxemia, esophageal intubation (AA)§	Yes
1989	10 yr/M	III	Dextrocardia, univentricular heart of right ventricular type	Cardiac catheterization	Dysrhythmia leading to asystole (NAA)	Yes
1991	11 days/F	V E	Extreme prematurity, peritonitis, necrotizing enterocolitis	Small bowel resection	Massive uncontrolled blood loss (NAA)	No
1992	8 yr/M	I	Vesicourethral reflux	Ureteroileal neocystostomy	Asystole during halothane induction (AA)§	Yes
1992	13 yr/F	IV	Tonsillar hyperplasia with obstructive breathing, trisomy 21	Tonsillectomy	Pulmonary hypertension, hypoxia and cardiac arrest after induction (NAA)§	No
1992	10 mo/F	III	Seizure disorder	Hemispherectomy	Sudden bradycardia and cardiac arrest, presumed air embolus (NAA)§	Yes
1993	14 yr/M	III	Spinal cord tumor	Resection of tumor	Massive blood replacement and hyperkalemia (NAA)§	Yes
1993*	1 days/M	IV	Hypoplastic left ventricle, PDA	Balloon atrial septostomy	Mechanical tear during catheterization, pericardial tamponade (NAA)‡	No
1994	9 yr/F	III	Severe neuromuscular scoliosis	Anterior spine instrumentation	Massive blood replacement, hyperkalemia (7.9 mEq/l) (NAA)§	Yes
1995*	7 yr/F	III	Subglottic stenosis	Rigid tracheoscopy, tracheal dilation	Asystole during halothane induction (AA)§	Yes
1996	25 days/M	V E	Extreme prematurity, ischemic bowel, sepsis	Small bowel resection	Septic shock, hemorrhage, and uncontrollable hypotension (NAA)	No
1996*	10 yr/M	IV	Acute myeloic leukemia, respiratory and renal failure	Bronchoscopy	Intrabronchial bleeding causing severe hypoxemia (NAA)	No
2000	4 yr/F	III	X-chromosome duplication syndrome, malfunctioning central intravenous catheter	Replacement of central access intravenous catheter	Ruptured coronary sinus during replacement of central venous catheter (NAA)‡	Yes
2001†	17 yr/M	III	S/P Fontan procedure, atrial flutter	TEE before cardioversion	Laryngospasm during MAC anesthesia (AA)§	No
2001	4 yr/M	III	Lumbar kyphosis, meningomyelocele, PDA	Posterior spinal instrumentation	Presumed air embolus (NAA)§	No
2001	2 yr/F	V E	Traumatic subdural hematoma	Craniotomy	Sudden ventricular fibrillation (NAA)	No
2002‡	4 yr/F	V E	Septic shock	Subtotal colectomy, insertion of Mahurkar (dialysis) catheter	Preexisting hemodynamic instability, infusion of vasopressors interrupted (battery failure) which resulted in severe hypotension/cardiac arrest (AA)§	No
2002	6 mo/M	V	Double outlet right ventricle	Balloon atrial septostomy	Sudden bradycardia during catheterization requiring "chest compression" (NAA)	Yes
2002	7 yr/M	V E	Car accident, abdominal bleeding, cardiac contusion	Exploratory laparotomy, partial hepatectomy	Hemorrhage, hypovolemia (NAA)	No
2002	12 yr/M	III	Severe neuromuscular scoliosis	Anterior and posterior spinal fusion	Coagulopathy, hemorrhage, hypovolemia, massive transfusion (NAA)§	No
2003	12 yr/F	II	Bilateral knee arthrofibrosis with immobility	Examination under anesthesia	Probable pulmonary embolism (NAA)§	No
2004	4 yr/M	IV	Mosaic trisomy, tricuspidal atresia, tethered spinal cord	Magnetic resonance imaging	Mainstem intubation, hypoxemia (AA)§	Yes
2005	14 mo/M	V E	Cyanotic heart disease, previous Norwood procedure	Microlaryngoscopy	Worsening of hypoxemia during anesthesia (NAA)§	Yes
2005	2 days/M	IV	Arnold-Chiari type III malformation; premature infant	Occipital craniotomy	Hemorrhage, hypovolemia (NAA)§	No
2005	17 yr/M	V E	Farm accident, massive internal hemorrhage, multiple degloving injuries extremities	Abdominal exploration, ligation external iliac artery and vein, left hip disarticulation	Hemorrhage, hypovolemia; open cardiac massage (NAA)	No

For our definitions of anesthesia attributed (AA) and non–anesthesia attributed (NAA), see Materials and Methods.

* Cardiac arrests not reported in our previous study[17] where we excluded all patients who experienced cardiac arrest during cardiac catheterization and bronchoscopy. † This is the only procedure performed during monitored anesthesia care (MAC). All other operations were performed during general anesthesia. ‡ NAA cardiac arrest caused by incident caused by surgical procedure/technique. § Patients who would be classified as "anesthesia related" according to the Perioperative Cardiac Arrest Registry definitions.

ASA PS = American Society of Anesthesiologists physical status; E = emergency procedure; PDA = patent ductus arteriosus; S/P = status post; TEE = transesophageal echocardiogram.

practice. Similarly, Morita *et al.*[23] found that the majority of perioperative CA in neonates could be attributed to underlying comorbidities rather than to anesthesia-related causes.

The number of anesthesia-attributed CAs in the current study is insufficient to meaningfully compare the causes of CA with the POCA report; indeed, the strength of the POCA Registry is the ability to analyze larger numbers of events. However, the pattern of causality seemed to be similar; of the 6 anesthesia-attributed perioperative CAs

Table 6. Perioperative Cardiac Arrests in Cardiac Procedures: Overview of Demographics, Procedural Factors, Causes of Cardiac Arrests, and Survival*

Year of CA	Age/Sex	ASA PS	Diagnosis and/or Operation	Presentation and/or Cause of CA	Survived
1989	17 mo/M	III	Anomalous origin of left coronary artery; severe LV dysfunction	Acute LV failure; patient unresponsive to pacing and CPR	No
1989	6 yr/M	III	DORV; atrioventricular valve insufficiency	LV failure; VF resistant to CPR	No
1990	16 mo/M	IV E	Univentricular heart; recurrent partial obstruction of St. Jude tricuspid valve	LV failure after cardiopulmonary bypass	No
1990	8 yr/F	III	Redo surgery for aorto–right pulmonary artery shunt	Severe bradycardia and CA	No
1991	2 days/F	IV E	Repair of severe congenital aortic and mitral stenosis; term infant with respiratory distress	Intraoperative severe hypoxia, bradycardia and asystole	No
1991	4 yr/M	III	Pulmonary atresia, ASD (common atrium), VSD, pulmonary atresia; dextrocardia	Upon completion of surgery profuse bleeding and CA	No
1993†	14 yr/M	III	S/P Ebstein anomaly in 1987; tricuspid regurgitation; replacement of tricuspid valve	Sudden onset of VF	Yes
1993†	14 yr/M	III	S/P Ebstein anomaly repair (see above); complete heart block 8 days after initial surgery	VF developed during permanent pacemaker insertion	Yes
1994	2 yr/M	IV	Tricuspid atresia, pulmonary stenosis; TGA; modified Fontan procedure	Hypoxemia due to noncardiogenic pulmonary edema	No
1994	1 yr/F	III	Supravalvular aortic stenosis; anoxic encephalopathy	Survived initial CPR in the operating room, later died of LV dysfunction	No
1995	17 yr/F	IV	Massive pulmonary artery tumor (sarcoma) embolus; embolectomy	Severe bradycardia and CA	Yes
1996	6 yr/M	3	Double inlet left ventricle; S/P modified Fontan procedure	Pulmonary embolism after induction (PEA)	No
1997	6 days/M	IV	Critical aortic stenosis; hypoplastic aortic arch; pulmonary valve stenosis; VSD, creation of aortopulmonary window; premature infant	Intractable LV failure	Yes
1997	5 days/F	III	PDA; poor LV function, mitral and aortic valves stenosis	Sudden intraoperative asystole	No
1998	1 days/M	IV E	Critical pulmonary stenosis; S/P RVOT reconstruction, posterior descending artery ligation, systemic to pulmonary shunt with synthetic graft from innominate to right pulmonary artery	Multiple VF-based CAs	Yes
1999	2 days/F	IV	Total anomalous pulmonary venous return, DORV; pulmonary atresia with hypoxia	Severe intraoperative hypoxia, hypotension and CA	No
2003	6 days/M	III	TGA, VSD; S/P arterial switch	Severe hypoxemia after chest closure; initiated extracorporeal membrane oxygenation	Yes

* Only patients who received chest compressions were included in this table, and excluded were patients who died because they failed weaning from cardiopulmonary bypass. † Identical patient; two cardiac arrests (CAs) during two separate procedures.

ASA PS = American Society of Anesthesiologists physical status; ASD = atrial septal defect; CPR = cardiopulmonary resuscitation; DORV = double-outlet right ventricle; E = emergency procedure; LV = left ventricular; PDA = patent ductus arteriosus; PEA = pulseless electrical activity; RVOT = right ventricular outflow tract; S/P = status post; TGA = transposition of great arteries; VF = ventricular fibrillation; VSD = ventricular septal defect.

in the current study (table 5), 3 (50%) were related to respiratory factors, 2 (33%) were related to medications (halothane), and 1 (17%) was related to equipment, etiologies that were all relatively common in the POCA report.[11]

Incidence of Perioperative CA

The incidence of anesthesia-attributed perioperative CA may be declining (all per 10,000): 3.0 between 1978 and 1982,[9] 1.4 between 1994 and 1997,[11] 0–1.5 for various age groups in 1999,[23] and 0.83 between 2000 and 2002,[16] although a recent report from Brazil makes this conclusion controversial.[18] Part of the controversy involves challenges in comparing the frequency of perioperative CA from among studies because the incidence greatly depends on both the characteristics of the reported surgical population and causes considered (anesthesia *vs.* non–anesthesia related, and whether cardiac operations were included in review) (table 8).[4,9–11,18] Our study demonstrates the impact of including cardiac operations on the incidence of perioperative CA (table 7); when ad-

Table 7. Estimated Increase in Risk of Perioperative Cardiac Arrest or Death for Cardiac *vs.* Noncardiac Surgery/Procedures

Age	Cardiac Arrest,† Odds Ratio (95% CI)	Death, Odds Ratio (95% CI)
0 to 30 days	11.5 (3.9–33.9)	10.2 (3.4–30.6)
	3.6 (1.0–12.9)‡	2.4 (0.6–9.7)‡
31 days to < 1 yr	47.1 (13.6–163.1)	§
	3.1 (0.3–30.2)‡	§
Overall < 1 yr	33.6 (14.8–75.9)	55.2 (19.5–156.4)
	6.9 (2.4–19.7)‡	8.6 (2.3–32.2)‡
1 to 3 yr	43.6 (14.9–127.9)	218.2 (27.9–1,706.3)
	13.1 (3.1–54.9)‡	65.5 (6.8–630)‡
4 to 9 yr	12.3 (3.6–42.2)	21.6 (5.4–86.4)
	9.2 (2.4–35.8)‡	16.2 (3.6–72.4)‡
10 to < 18 yr	30.9 (10.4–92.1)	21.6 (5.1–90.4)
	20.6 (6–70.5)‡	7.2 (0.8–61.6)‡
Total,† 0 to < 18 yr	26.2 (15.8–43.6)	42.2 (22.4–79.7)

† Odds ratio and 95% confidence interval (CI) after adjusting for age group. ‡ Odds ratio and 95% CI when "failure to wean from cardiopulmonary bypass" patients were excluded from calculation. § There were no deaths in patients undergoing noncardiac surgery in the age group 31 days to < 1 yr, therefore odds ratios are not calculated.

justed for age, our patients undergoing cardiac operations had a 26-fold higher probability of experiencing a perioperative CA. Therefore, to accurately interpret the reported incidence of perioperative CA, it is clearly important to define the underlying case mix.

Our overall incidence of perioperative CA (8.6 per 10,000 anesthetics) was comparable to some reports[5,10,14] but higher than the initial POCA report (2.7 per 10,000).[11] A recent study from a tertiary Brazilian teaching institution reported a high overall incidence of perioperative CA (22.9 per 10,000) for a wide mix of cases including cardiac procedures.[18] In contrast to the current findings, these investigators found a high incidence of CA during thoracic (67 per 10,000), gastroenterologic (54 per 10,000), and neurosurgical (38 per 10,000) operations.[18] Their incidence of CA totally attributable to anesthesia was 2.6 per 10,000,[18] which is higher than in the current study (0.65 per 10,000) or in the POCA report (1.4 per 10,000).[11] The lower incidence of anesthesia-attributed CA in our study compared with the POCA Registry may be attributed to differences in the definition of anesthesia-attributed causes. However, if our definition is expanded to reflect the criteria used by the POCA Registry, our incidence of CA (1.5 per 10,000) is similar to that of the POCA report.[11] Of note, our incidence of anesthesia-attributed CA was also similar to that in our previous study of a general noncardiac surgery population that was primarily (approximately 95%) composed of adults (0.5 per 10,000).[17]

Several factors affected the incidence of perioperative CA. The incidence during cardiac operations (127.3 per 10,000) was very high, which may reflect the relative complexity of patients in this tertiary referral center, especially the neonates (in whom the incidence of perioperative CA was very high [435 per 10,000]). When those patients who were unable to be weaned from CPB were excluded, the CA rate was decreased but still substantial (40.1 per 10,000), approximately 14-fold higher than the rate during noncardiac surgery. A most recent report by Braz *et al.*[18] reported 33.4 CA per 10,000 cardiac operations; however, it is not known whether this includes CA due to inability to wean from the CPB. The severity of underlying disease was clearly an important factor in our study, because 77 of the total of 80 perioperative CAs (96.3%) were in patients classified as ASA PS of III or greater. Regardless of the type of procedure, most patients who experienced CA (88%) had congenital heart disease. For patients classified as ASA PS I or II undergoing noncardiac surgery, the incidence of CA was very low (0.3 per 10,000). Trends in the incidence of perioperative CA over time were not apparent over the study period, although the small number of events limits the ability to detect any such trend. Because most perioperative CAs were related to the severity of underlying disease, this finding is perhaps not surprising.

We confirmed previous findings that the incidence of perioperative CA was highest in neonates and infants, and beyond the first year of life, age does not noticeably affect incidence of CA.[5,9,10,14,23] For example, Olson and Hallen[5] reported (all per 10,000) incidences of 17 perioperative CAs in infants, 4.6 between 1 and 9 yr, and 3.0 from ages 10 to 59 yr. Our incidence of CA in children undergoing noncardiac procedures was very high for neonates (39.4 per 10,000) and much lower for all other age groups (table 2). The overall incidence of perioperative CA was actually lower (2.9 per 10,000) than in a previous report of our overall noncardiac surgical population that included primarily (approximately 95%) adults (4.3 per 10,000), which used the same definitions of CA and the same ascertainment strategy.[17] Therefore, children older than 1 yr do not seem to be at increased

Table 8. Previous Studies of Perioperative Cardiac Arrests in Children

				Overall Incidence of CA per 10,000		Anesthesia-attributed CAs per 10,000	
Reference and Study Type	Age, Number of Patients, Types of Operations	Study Years	Perioperative Time Studied	Incidence	Mortality	Incidence	Mortality
Rackow *et al.*,[14] retrospective	< 12 yr, 34,499, No cardiac surgery	1947–1956	Perioperative (anesthesia + PACU)	7.2 (overall), 16.2 (< 1 yr), 6.0 (1 to 12 yr)	4.9 (68%)	5.5 (overall), 13.9 (< 1 yr), 4.3 (1 to 12 yr)	2.9
Salem *et al.*,[20] retrospective	Not reported	1960–1972	Perioperative (under care of anesthesia team)	Not reported	Not reported	Total 73 CA, 2.8 in one hospital	24 died (33%)
Keenan and Boyan,[4] survey	< 12 yr, 12,712, All surgeries	1969–1983	Intraoperative	4.7 (< 12 yr)	1.6 (< 12 yr)	4.7 (< 12 yr)	1.6 (< 12 yr)
Olsson and Hallen,[5] retrospective	250,543 (P&A), No cardiac surgery	1967–1984	Intraoperative (during anesthesia)	6.8 (overall) (P&A), 17.0 (< 1 yr), 4.6 (1 to 9 yr), 3.0 (10 to 19 yr)	2.4 (P&A)	4.6 (P&A)	0.4 (P&A)
Tiret *et al.*,[9] survey	< 15 yr, 40,240, All surgeries	1978–1982	Perioperative (< 24 h after anesthesia)	3.0 (0 to 14 yr) (all anesthesia attributed)	0.2 (0 to 14 yr)	3.0 (0 to 14 yr), 19.0 (< 1 yr), 2.1 (1 to 14 yr)	0.2 (0 to 14 yr), 0 (< 1 yr), 0.3 (1 to 14 yr)
Cohen *et al.*,[10] survey	< 16 yr, 29,220, All surgeries	1982–1987	Perioperative (intraoperative + PACU)	7.2 (overall), 83.1 (< 1 mo), 15.7 (1 to 12 mo), 5.2 (1 to 5 yr), 5.6 (6 to 10 yr), 5.3 (11+ yr)	3.8 (overall), 83.1 (< 1 mo), 7.9 (1 to 12 mo), 3.0 (1 to 5 yr), 1.4 (6 to 10 yr), 1.8 (11+ yr)	Not reported	Not reported
Keenan and Boyan,[15] retrospective	< 12 yr, 13,693, All surgeries	1983–1990	Intraoperative	Not reported	Not reported	2.9 (overall), 9.2 (< 1 yr), 0 (> 1 yr)	Not reported
Morray *et al.*,[11] prospective registry	< 18 yr, 1,089,200 (estimated), All surgeries	1994–1997	Perioperative (anesthesia + PACU)	2.7	Not reported	1.4	0.4 (26%)
Tay *et al.*,[27] survey	10,000, All surgeries	1997–1999	Perioperative (under care of anesthesia team)	4.0	3.0	0	0
Morita *et al.*,[23]* survey	732,788 (P&A), All surgeries	1999	Perioperative (< 7 days)	54.2 (< 1 mo), 8.8 (< 12 mo), 5.1 (< 5 yr), 2.6 (< 18 yr)	42.8 (< 1 mo), 2.45 (< 12 mo), 2.54 (< 5 yr), 1.7 (< 18 yr)	0.0 (< 1 mo), 1.47 (< 12 mo), 0.25 (< 5 yr), 0.34 (< 18 yr)	0.0 (< 1 mo), 0.0 (< 12 mo), 0.0 (< 5 yr), 0.17 (< 18 yr)
Murat *et al.*,[16] survey	24,165, No cardiac surgeries	2000–2002	Perioperative (intraoperative + PACU)	3.3 (overall), 10.9 (0 to 1 yr), 1.6 (1 to 7 yr), 2.9 (8 to 16 yr)	0.4 (overall)	0.8	0
Braz *et al.*,[18] retrospective	15,253, All surgeries	1996–2004	Perioperative (intraoperative + PACU)	22.9 (overall), 201 (< 1 mo), 42 (< 12 mo), 9 (1 to ≤ 12 yr), 9 (13 to ≤ 17 yr)	9.8 (overall)	4.6 (anesthesia attributed and contributed)	0

P&A: these studies included pediatric and adult patients; however, we report incidence and mortality only for the pediatric population (if not indicated otherwise).
* Japanese text; information obtained from English translated abstract (denominators for pediatric populations not reported in abstract).
CA = cardiac arrest; PACU = postanesthesia care unit.

risk for perioperative CA compared with adults in our practice.

Mortality after Perioperative CA

As with perioperative CA incidence, reported mortality after perioperative CA depends on whether studies include anesthesia-attributed arrests and whether cardiac procedures were analyzed (table 8).[4,9–11] In our study, a child undergoing cardiac surgery and experiencing CA had 42-fold higher odds of dying compared with CA occurring during a noncardiac operation (table 7). The mortality rate after CA was lower for noncardiac operations (54%) than for cardiac operations (91%). The single most common cause of death in patients undergoing cardiac procedures was a failure to wean the patient from CPB, and mortality was related to underlying cardiac disease in every other case (table 6). Although, to the best of our knowledge, other studies reporting mortality rates for perioperative CA after congenital heart surgery are not available for comparison, reported mortality rates for CA after congenital heart surgery (*i.e.*, that of CA occurring in the intensive care unit) ranges from 59% to 86%.[24–26] The mortality rates associated with perioperative CA in our study during both noncardiac and cardiac procedures declined with child's age, similar to previous reports.[10,23]

Compared with CA attributed to nonanesthetic causes, mortality after anesthesia-related CA is typically lower (table 8), a finding that we have confirmed. In the current study, the mortality for anesthesia-related CAs was 0.22 per 10,000, similar to that in the POCA report (0.36 per 10,000)[11] and comparable to the report of Morita *et al.*[23] (0.17 per 10,000). The single most common cause of death in children undergoing noncardiac procedures was hemorrhage (6 of 14 deaths [43%]) (table 5). In univariate analysis, mortality was associated with an ASA PS of 3 or greater, the need for preoperative mechanical ventilation, and hemorrhage as a cause of arrest, which points toward factors related to the patients' disease and the procedure as important, rather than to anesthesia-related factors. In the POCA Registry, higher ASA PS was a strong predictor of death after anesthesia-related CAs.[11]

Study Limitations

This is a retrospective study with the inherent limitation of the potentially inconsistent nature of information in the medical record. First, the presence of mandatory reporting for immediate perioperative CA encourages contemporaneous reporting of data, but we cannot exclude that relevant information was omitted from the description of events or that case ascertainment was not complete. Second, Mayo Clinic is a tertiary referral institution, and this practice is likely not representative of the general population of children undergoing surgery. Our surgical population as a whole and our cardiac surgical population in particular are weighted toward fewer routine procedures. This factor can be expected to bias toward a higher frequency and mortality of perioperative CAs. Third, the absolute number of events identified, even in this relatively large series, was small, limiting the ability to make inference such as trends over time with confidence. Small numbers also prevented us from performing multivariate analysis. Such analysis would have allowed for the control of confounding between important variables such as age and complexity of procedure or coexisting disease. For example, although it is apparent from this and other studies that age is an important risk factor for both perioperative CA and mortality, the observed increase in risk may be a reflection of the complexity of procedures and coexisting disease frequently present in infants and neonates who require surgery. Finally, retrospective assignment of etiology to anesthesia related or non–anesthesia related is dependent on the subjective judgment and is dependent to some extent on the accuracy of the medical record. This limitation is inherent in all studies of this type. However, the fact that all perioperative CAs are reviewed by the Performance Review Committee that specifically queries for factors related to anesthetic management makes it more likely that the information necessary to accurately assign etiology was available.

Summary

Over an approximately 17-yr period, the majority of perioperative CAs in children requiring anesthesia services at Mayo Clinic Rochester were caused by factors not related to anesthesia, in distinction to the findings of the initial report from the POCA Registry.[11] The incidence of perioperative CA was many-fold higher in children undergoing cardiac procedures, suggesting that definition of case mix is necessary to accurately interpret epidemiologic studies of perioperative CA in children. Neonates and infants continue to be at the highest risk for perioperative CA and death during procedures requiring anesthesia services.

The authors thank members of the Department of Anesthesiology who over years participated in collecting and maintaining information in the Performance Improvement Database. They also thank Dianne Shimek (Surgical Index Retrieval Specialist, Mayo Clinic, Rochester, Minnesota), Carl Walin, M.S. (Senior Programmer Analyst, Mayo Clinic Information Services, Mayo Clinic), Judy Lenoch (Data Management Specialist, Division of Cardiovascular Surgery Research, Mayo Clinic), and Linda Trogstad-Bach (Data Collection Assistant, Division of Cardiovascular Surgery Research, Mayo Clinic) for help in data retrieval.

References

1. Beecher HK, Todd DP: A study of the deaths associated with anesthesia and surgery. Ann Surg 1954; 140:2–34
2. Clifton BS, Hotten WI: Deaths associated with anaesthesia. Br J Anaesth 1963; 35:250–9
3. Graff TD, Phillips OC, Benson DW, Kelley E: Baltimore Anesthesia Study Committee: Factors in pediatric anesthesia mortality. Anesth Analg 1964; 43: 407–14
4. Keenan RL, Boyan CP: Cardiac arrest due to anesthesia: A study of incidence and causes. JAMA 1985; 253:2373–7
5. Olsson GL, Hallen B: Cardiac arrest during anaesthesia: A computer-aided study in 250,543 anaesthetics. Acta Anaesthesiol Scand 1988; 32:653–64
6. Romano PE, Robinson JA: General anesthesia morbidity and mortality in eye surgery at a children's hospital. J Pediatr Ophthalmol Strabismus 1981; 18:17–21
7. Smith RM: The pediatric anesthetist, 1950–1975. Anesthesiology 1975; 43: 144–55
8. Tiret L, Desmonts JM, Hatton F, Vourc'h G: Complications associated with anaesthesia: A prospective survey in France Can Anaesth Soc J 1986; 33:336–44
9. Tiret L, Nivoche Y, Hatton F, Desmonts JM, Vourc'h G: Complications related to anaesthesia in infants and children: A prospective survey of 40240 anaesthetics. Br J Anaesth 1988; 61:263–9
10. Cohen MM, Cameron CB, Duncan PG: Pediatric anesthesia morbidity and mortality in the perioperative period. Anesth Analg 1990; 70:160–7
11. Morray JP, Geiduschek JM, Ramamoorthy C, Haberkern CM, Hackel A, Caplan RA, Domino KB, Posner K, Cheney FW: Anesthesia-related cardiac arrest in children: Initial findings of the Pediatric Perioperative Cardiac Arrest (POCA) Registry. Anesthesiology 2000; 93:6–14
12. Morray JP: Anesthesia-related cardiac arrest in children: An update. Anesthesiol Clin North Am 2002; 20:1–28
13. Lagasse RS: Anesthesia safety: Model or myth? A review of the published literature and analysis of current original data. Anesthesiology 2002; 97:1609–17

14. Rackow H, Salanitre E, Green LT: Frequency of cardiac arrest associated with anesthesia in infants and children. Pediatrics 1961; 28:697–704

15. Keenan RL, Boyan CP: Decreasing frequency of anesthetic cardiac arrests. J Clin Anesth 1991; 3:354–7

16. Murat I, Constant I, Maud'huy H: Perioperative anaesthetic morbidity in children: A database of 24,165 anaesthetics over a 30-month period. Paediatr Anaesth 2004; 14:158–66

17. Sprung J, Warner ME, Contreras MG, Schroeder DR, Beighley CM, Wilson GA, Warner DO: Predictors of survival following cardiac arrest in patients undergoing noncardiac surgery: A study of 518,294 patients at a tertiary referral center. ANESTHESIOLOGY 2003; 99:259–69

18. Braz LG, Braz JR, Modolo NS, do Nascimento P Jr, Bruschi BA, de Carvalho LR: Perioperative cardiac arrest and its mortality in children: A 9-year survey in a Brasilian tertiary teaching hospital. Ped Anesth 2006; 16:860–6

19. Bonoli P, Grillone G, Fossa S, Franceschelli N, Lari S, Leykin Y, Nastasi M, Zanoni A: Complications of pediatric anesthesia: Survey carried out by the Study Group SIAARTI for anesthesia and intensive therapy in children [in Italian]. Minerva Anestesiol 1995; 61:115–25

20. Salem MR, Bennett EJ, Schweiss JF, Baraka A, Dalal FY, Collins VJ: Cardiac arrest related to anesthesia: Contributing factors in infants and children. JAMA 1975; 233:238–41

21. Morray JP, Geiduschek JM, Caplan RA, Posner KL, Gild WM, Cheney FW: A comparison of pediatric and adult anesthesia closed malpractice claims. ANESTHESIOLOGY 1993; 78:461–7

22. Bhananker SM, Ramamoorthy R, Posner KL, Domino KB, Morray JP: Changing profile of anesthesia-related cardiac arrests in children: Update from Pediatric Peri-Operative Cardiac Arrest (POCA) Registry (abstract). ANESTHESIOLOGY 2005; 103:A1310

23. Morita K, Kawashima Y, Irita K, Kobayayashi T, Goto Y, Iwao Y, Seo N, Tsuzaki K, Dohi S: Perioperative mortality and morbidity in 1999 with a special reference to age in 466 certified training hospitals of Japanese Society of Anesthesiologists: Report of Committee on Operating Room Safety of Japanese Society of Anesthesiologists [in Japanese]. Masui 2001; 50:909–21

24. Slonim AD, Patel KM, Ruttimann UE, Pollack MM: Cardiopulmonary resuscitation in pediatric intensive care units. Crit Care Med 1997; 25:1951–5

25. Gillis J, Dickson D, Rieder M, Steward D, Edmonds J: Results of inpatient pediatric resuscitation. Crit Care Med 1986; 14:469–71

26. Rhodes JF, Blaufox AD, Seiden HS, Asnes JD, Gross RP, Rhodes JP, Griepp RB, Rossi AF: Cardiac arrest in infants after congenital heart surgery. Circulation 1999; 100:II194–9

27. Tay CL, Tan GM, Ng SB: Critical incidents in paediatric anaesthesia: An audit of 10 000 anaesthetics in Singapore. Paediatr Anaesth 2001; 11:711–8